Helicopter Hoist Attitude Control Systems

Liam Stransky, David Shaker, Cameron Brossart, Michael Konshin, Ashley Gray

San Diego State University
Aerospace Engineering — Advancing the Dream of Flight

Problem Statement

United States Coast Guard helicopters carry out rescue missions serving in remote and inaccessible environments. Complex rotor wash flow propagated by the rotor blades creates an unpredictable and uncontrollable aerodynamic torques on the hoist load that develops unstable rotations. With current equipment and practices, there is no ideal solution to dynamic instabilities as they develops over time.

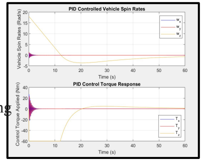
Design Criteria & Proposed Solution

Our device will utilize gimbaling flywheels to produce counteractive torque and dynamically neutralize the spin of the hoist load. A combination of flywheels with ideally defined degrees of freedom will utilize complex control laws to produce continuous & constant magnitude torque counteractive to aerodynamic disturbances about the vertical axis.

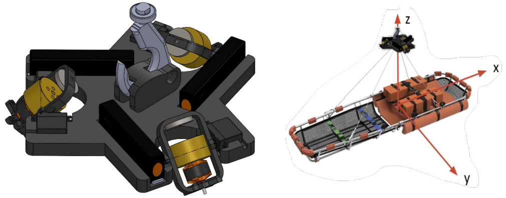
Alternate & current solution methods were analyzed and design criteria for an improved system were determined:

- ≈55 Nm of torque
- > 60 minutes battery life
- < 50 lbs device weight
- < 1ft^3 volume
- Waterproof
- Reference heading tracking
- etc.

Example Response Goal:



Sponsors

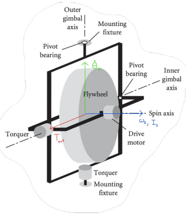


Demonstrator Characteristics

The final scaled demonstrator design utilizes three 1-pound brass flywheels inside 3D-printed gimbal frames. Each gimbal has an embedded motor to power the flywheels at a nominal rpm and can produce up to 3 Nm of torque at low gimbal rates, with a continuous power draw of roughly 22 Watts. Performance is estimated roughly 20 magnitudes smaller than full-scale, showcasing the advantages & capabilities of CMGs.

Proposed Solution: Control Moment Gyroscopes

Theory on dynamic gyroscopic motion presents the governing principles that altering the angular momentum vector of a spinning flywheel will produce an output torque in an orthogonal direction. As the flywheel spins in a specified direction, the entire system will gimbal about a perpendicular axis to develop a change in angular momentum to alter total system attitude.

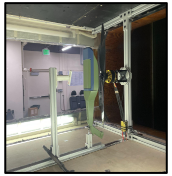


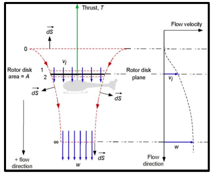
$$\left(\frac{d\mathbf{H}_G^{(v)}}{dt}\right)_{rel} + \boldsymbol{\omega}\times\mathbf{H}_G^{(v)} + \left(\frac{d\mathbf{H}_{G_w}^{(w)}}{dt}\right)_{rel} + \boldsymbol{\omega}\times\mathbf{H}_{G_w}^{(w)} = \mathbf{M}_{G_{net}}$$

$$C\dot{\omega}_z - H^{(w)}\dot{\theta}\sin\theta + \dot{H}^{(w)}\cos\theta - (H^{(w)}\cos\phi\sin\theta + A\omega_x)\omega_y + (H^{(w)}\sin\phi\sin\theta + B\omega_y)\omega_x = M_{G_{net_z}}$$

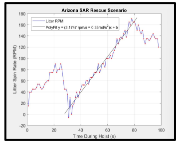
Research and Testing

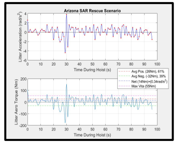
Model testing was conducted in the San Diego State Low Speed Wind Tunnel to validate rotor wash effects. A model litter was placed at varying distances from the rotors to derive a relationship between litter torque measured via a tachometer and distance. Eight tests across six distances from 4.5 to 16.5 inches from the fuselage were conducted to confirm that varying intensity hoist litter spin rate is evident underneath the helicopter.

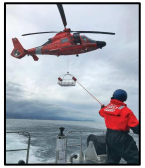




Rescue footage from various case studies were analyzed to characterize the angular acceleration as well as approximate expected torque figures.







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